APSCAM - A Novel Sensor to Monitor Railway Earthworks: Energy Harvesting Case Study

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Agenda

- Background
- APSCAM system introduction
- Architecture and power budget
- Design of solar PV energy harvesting and storage
- Conclusions

Introduction

- Conekt …
  - is a wholly-owned business unit of ZF TRW
  - was established as a trading entity in 2001
  - can trace its origins to the Lucas Research & Development Centre
  - enables leading companies to deliver winning products in a diverse range of industries, including Aerospace, Automotive, Defence, Intelligent Transport Systems, Rail, Energy, Commercial & Off-Highway Vehicles and Motorsport
  - operates a UKAS accredited Test Laboratory that provides a comprehensive suite of product validation services
  - employs approximately 100 professional engineers and technologists

Conekt Services

- Conekt delivers a complete engineering service from concept design through to validation testing and low volume product supply
  - **Product Development**
    - Technology evaluation, consultancy, design and analysis, safety analysis and management, collaborative R&D projects
  - **Product Validation**
    - Environmental testing, EMC testing, instrumentation, advanced test
  - **Product Reliability**
    - Failure analysis and investigation, reliability assessment and improvement, materials testing
  - **Product Supply**
    - Low volume product supply of adapted ZF TRW products to the automotive, commercial vehicle, motorsport & off-road vehicle markets

Background

- Conekt is developing a novel optical sensor system concept “APSCAM” for monitoring slippage of railway earthworks
- The sensor must use solar PV energy harvesting (EH) to ensure continuous service without battery replacement
- This case study describes the design process of the EH system to ensure successful operation
- The APSCAM project was funded by the Future Railway programme as part of its “Remote Condition Monitoring” challenge.
- The Future Railway programme www.futurerailway.org is a collaboration between Network Rail and RSSB working with industry and the supply chain to develop and deliver the UK Rail Technical Strategy (RTS).

APSCAM System Introduction

APSCAM Introduction

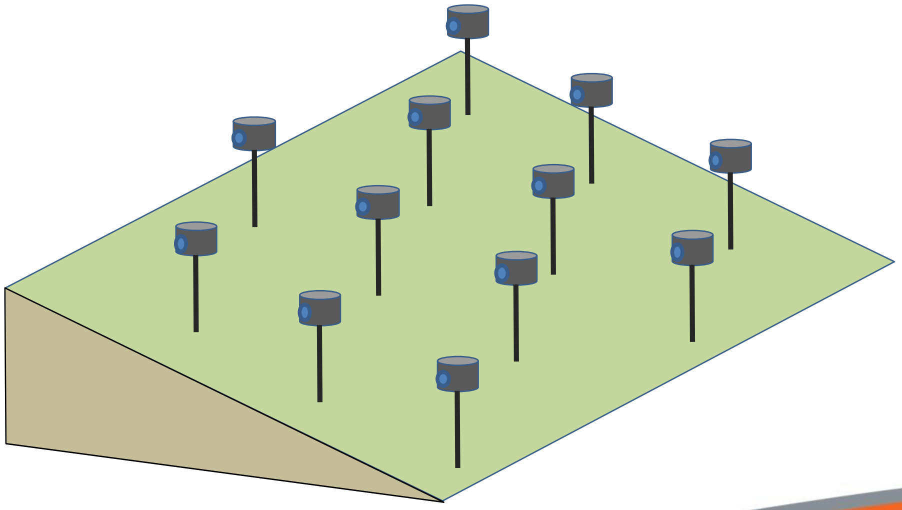
- “Array of Position Sensing Cameras” (APSCAM) is a novel sensing system to monitor railway earthworks for subsidence and slippage so that trains can be warned and repairs carried out.

Image: Peter Wasp [CC BY-SA 2.0 (http://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons

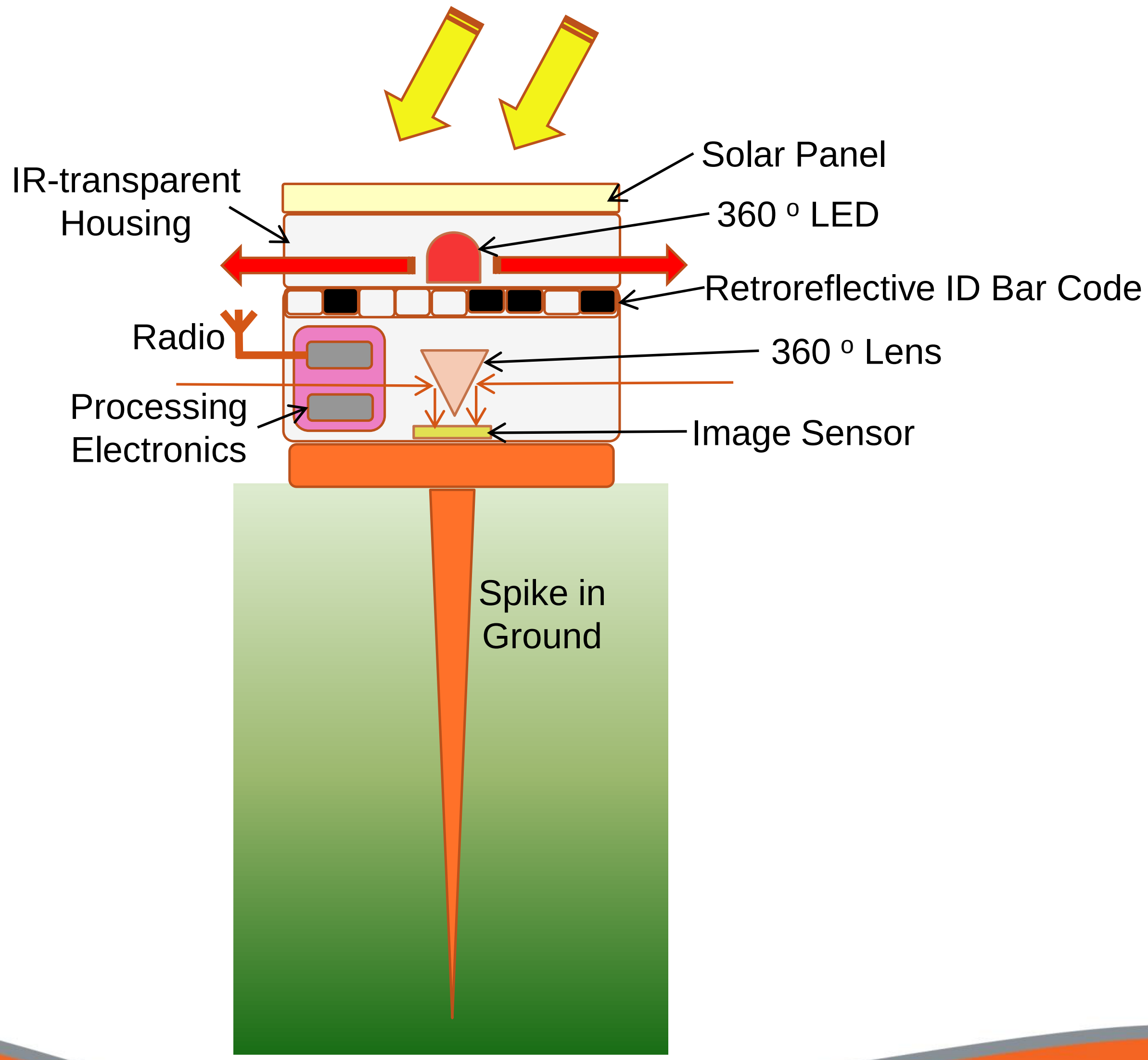
- APSCAM is an alternative to other monitoring technologies based on tilt sensors or precision satellite positioning

APSCAM Key Features

- Array of low cost cameras with 360° vision
- Each camera can see several others and note their relative positions
- Cameras record images in synchronism with pulsed infra-red light
- Each unit has a retroreflective bar code
- The bar code is detected by the other cameras
- Gives a unique identifier plus relative position
- Camera modules communicate wirelessly with a trackside data hub



APSCAM Sensor Module Concept



APSCAM System Benefits

- Provides a simple, robust, inexpensive system for accurately monitoring movement of earthworks
- Uses readily-available components and techniques
- Can be extended to cover any size of area by increasing the number of sensor modules employed
- Uses harvested energy to provide indefinite powering
- Is robust to “accidental” displacements of individual sensor modules
- Does not rely on GPS or similar power-hungry GNSS technologies to determine the device position
- Gives potential to monitor the positions of other natural or infrastructure objects (trees, gates, fences, masts etc.)

APSCAM architecture and power budget

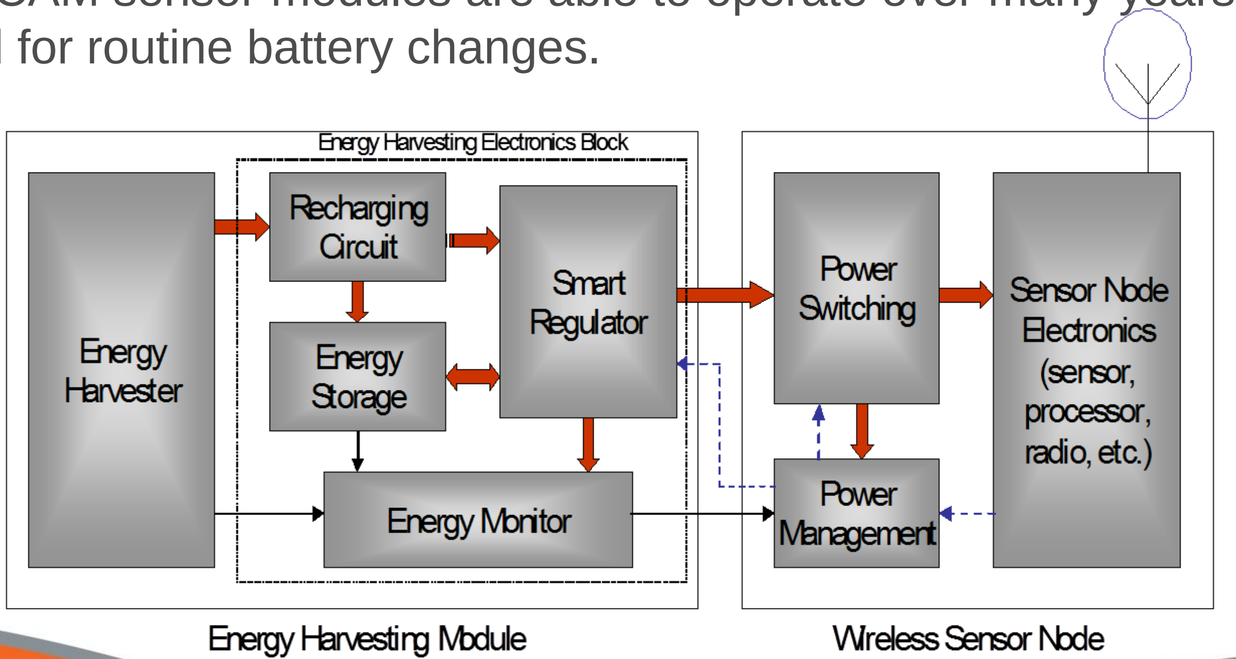
APSCAM – Key Building Blocks

The APSCAM module comprises the following main components:

- An imaging camera with 360° field of view
- An illuminating IR LED
- An image processing module, which can detect the positions of the other modules within the image, and any movements
- A radio module for transmitting data to the data collection hub
- A power supply sub-system

APSCAM Power Supply Sub-System

- The power supply sub-system of the APSCAM sensor module comprises:
  - An Energy Harvester (PV cell)
  - A battery for storing the electrical energy derived from the solar cell and providing power to the rest of the sensor module.
- The use of power derived from energy harvesting will ensure that the APSCAM sensor modules are able to operate over many years without the need for routine battery changes.



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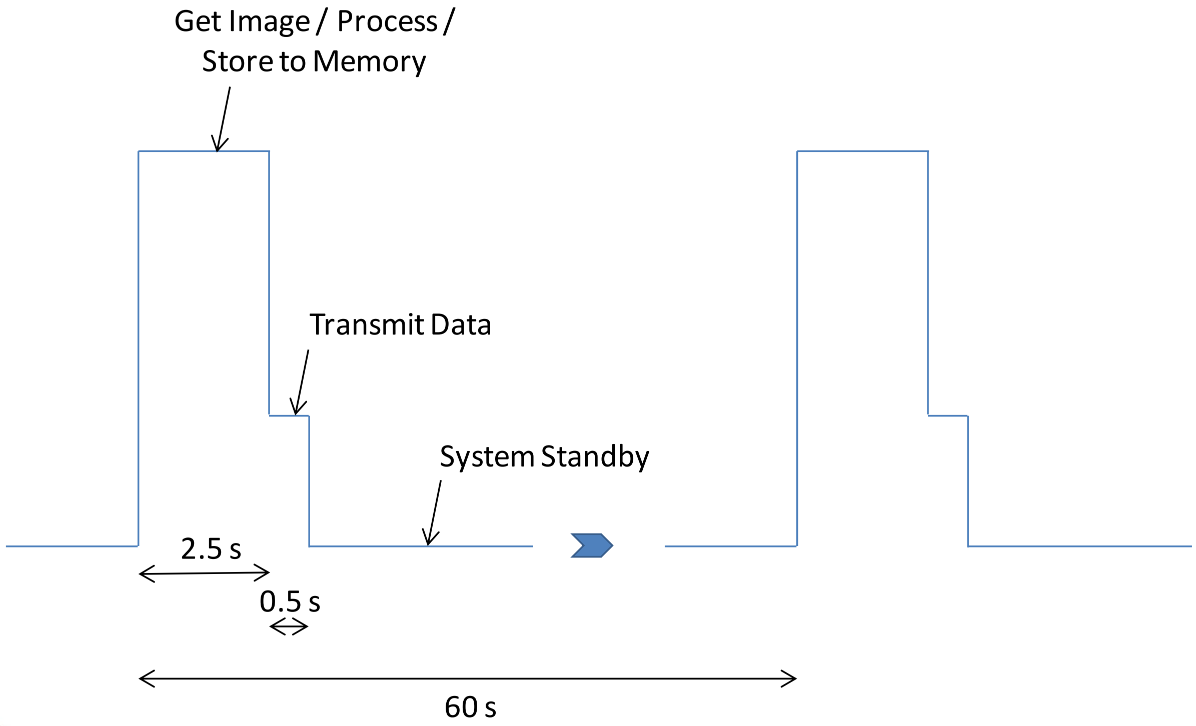
Duty Cycle

- The duty cycle must be determined to calculate average and peak power consumption
- This is done by calculating the power consumption of the key system functions and then determining the proportion of time that each is active.



Average and Peak Power Consumption

Sub-module	Average Power (mW)	Peak Power (mW)	Average Current at 3.6V (mA)	Peak Current at 3.6V (mA)
Imaging / Sensing	5.8	300	1.6	83.3
Processing / Memory	6.5	120	1.8	33.3
Radio Transceiver	0.5	60	0.1	16.7
Total	12.8	(480)	3.5	(133.3)

Average power

Peak power assumes worst case: all modules operate at the same time
- Unlikely in practice

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Choice of Energy Harvesting

- With an average current at 3.6 V of 3.5 mA, over a year this is 3.5 x 24 x 365 = 30660 mAh or approx. 30.5 Ah
  - This is beyond the capacity of a small primary battery in each sensor, even if it is replaced every year

- So the APSCAM system needs energy harvesting

- Possible EH energy sources are vibration, thermal and solar PV
  - There is insufficient vibration as the APSCAM units are fixed in the ground
  - There is no consistent temperature difference to exploit

- The choice is therefore solar PV

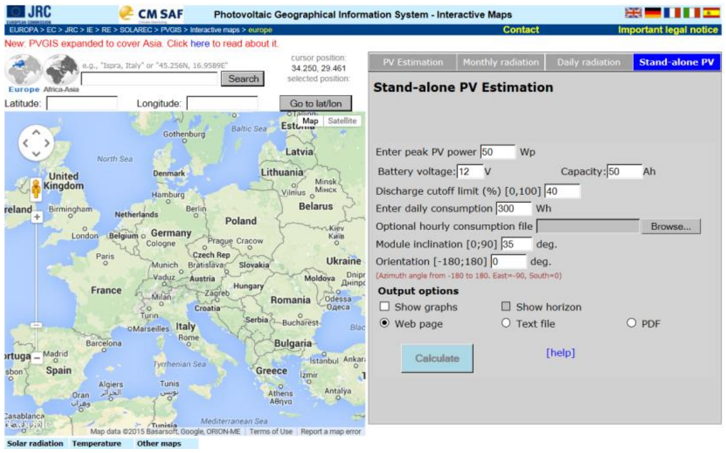
Design of Solar PV Energy Harvesting and Storage

Designing the EH

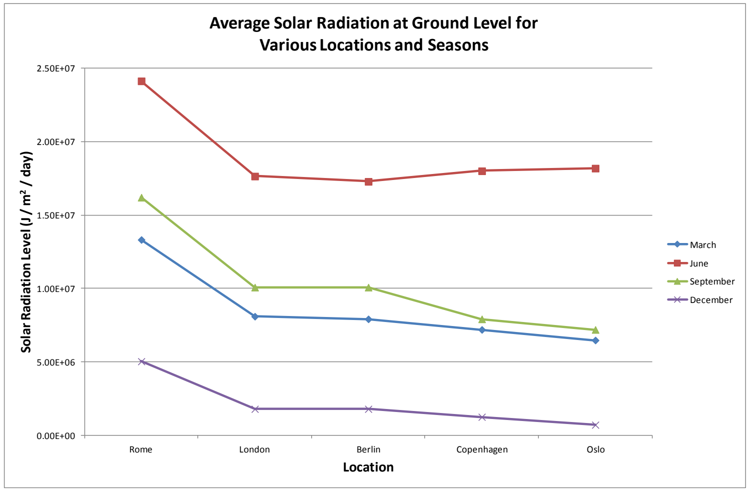
- We now know the peak and average power demand of the sensing system.
- The solar PV EH system must, on average, be able to supply the required total energy under all expected conditions.
- Energy storage (in this case a rechargeable battery) is needed to store the surplus daytime harvested energy, supply the peak demand and to supply the sensing system at night.
- Storage must be sized to accommodate the worst case for PV generation – mid winter with short days, low sun and poor weather.

PV power generation estimation

- A very useful resource is the "Photovoltaic Geographical Information System" (PVGIS) which is provided by the European Commission as an independent source of PV data
- This enables the PV generated energy to be compared for any location in Europe, taking into account daily, seasonal and weather variations, the type of PV panel and amount of energy storage available.
- The estimator enables the PV panel and storage to be sized so that under worst case conditions there is still enough energy available to power the load.



http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php



APSCAM PV Example (1)

- Location: London, latitude 51°30' N
- Nominal peak power of the PV system: 1 W
- Inclination of modules: 0 degrees (e.g. horizontal)
- Battery size: 3 V, 1 Ah
- Consumption per day: 0.31 Wh (12.8 mW average x 24h)

Month	% days full	% days empty
1	51	0
2	95	0
3	100	0
4	100	0
5	100	0
6	100	0
7	100	0
8	100	0
9	100	0
10	100	0
11	78	0
12	52	0

% of days in each month when battery was full

% of days in each month when battery was empty

Battery never empty so OK

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APSCAM PV Example (2)

- Location: Aberdeen, latitude 57° N
- Nominal peak power of the PV system: 1 W
- Inclination of modules: 0 degrees (e.g. horizontal)
- Battery size: 3 V, 1 Ah
- Consumption per day: 0.31 Wh

Further north

Month	% days full	% days empty
1	68	13
2	96	0
3	100	0
4	100	0
5	100	0
6	100	0
7	95	0
8	66	17
9	47	37
10	26	35
11	29	28
12	55	23

Battery is often empty in winter – not enough power for APSCAM sensor

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APSCAM PV Example (3)

- Location: Aberdeen, latitude 57° N
- Nominal peak power of the PV system: 1.5 W
- Inclination of modules: 0 degrees (e.g. horizontal)
- Battery size: 3 V, 4 Ah
- Consumption per day: 0.31 Wh

Increase power of PV panel

Increase storage capacity

Month	% days full	% days empty
1	72	0
2	100	0
3	100	0
4	100	0
5	100	0
6	100	0
7	98	0
8	70	0
9	53	0
10	35	0
11	42	0
12	61	0

Battery now never empty so OK

Conclusions

- APSCAM is a novel sensing system for monitoring railway earthworks
- A methodology for developing a power budget and sizing a PV EH system with energy storage has been presented
- The next stage will be to review datasheets for PV panels and batteries to choose the most suitable
- Work will also continue to develop the concept further to maximise performance and minimise power consumption

Thank you !!!

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